THE INDARRI FALLS TRAVERTINE DAM, LAWN HILL CREEK, NORTHWEST QUEENSLAND, AUSTRALIA

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ABSTRACT

Indarri Falls is a spectacular travertine dam which impounds Lawn Hill Creek, a perennial karst stream draining the Barkly Tableland in northwest Queensland, Australia. The dam is at least 13·5 m high, making it the largest feature of its kind known in Australia. Carbonate precipitation at the Falls is favoured by downstream changes in the bulk chemistry of the karst spring waters which feed the Creek, although deposition at the microenvironmental level may be encouraged by biological factors. The dam has dramatically altered the hydrology and geomorphology of the area, transforming the middle reaches of Lawn Hill Creek from a fluvial to a lacustrine environment. © 1997 by John Wiley & Sons, Ltd.

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INTRODUCTION

Arid and semi-arid karsts are arguably the poorest known of the world's karst terrains (Jennings, 1983; Ford and Williams, 1989, p. 467). Even in Australia, where extensive tracts of semi-arid karst can be found right across the continent, the remote nature of these landscapes has meant that research efforts there have been severely restricted. One aim of this note, therefore, is to add to the limited information on semi-arid karst by describing Indarri Falls, a travertine dam in the Barkly karst of northern Australia (Figure 1a). This is perhaps the largest feature of its kind on the continent, and one of the most spectacular karst phenomena in Australia. A second aim is to supplement the limited knowledge of travertine deposits located outside the mid-latitudes. Most studies of travertine have been undertaken in the temperate regions of Europe and north America and as a result little is known of the mechanisms and morphology of travertine deposition in the tropics.

INDARRI FALLS

Location and geomorphological setting

Indarri Falls (18°41′S, 138°29′E) is a travertine dam which impounds the middle reaches of Lawn Hill Creek, one of several perennial karst streams draining the northeastern edge of the Barkly Tableland in far northwest Queensland (Figure 1a). This part of the Barkly Tableland is largely developed on Cambrian Thorntonia Limestone. However, the edge of the upland is composed of a narrow band of Proterozoic Constance and Widdallion Sandstones. Where it crosses from the Tableland to the alluvial plains of the Carpentaria Lowlands, Lawn Hill Creek has cut a gorge through the Constance Sandstone. For a distance of at least 10 km within and below the gorge there occur extensive ancient and modern travertine deposits. The largest and most spectacular of these is that forming Indarri Falls (Figure 2).

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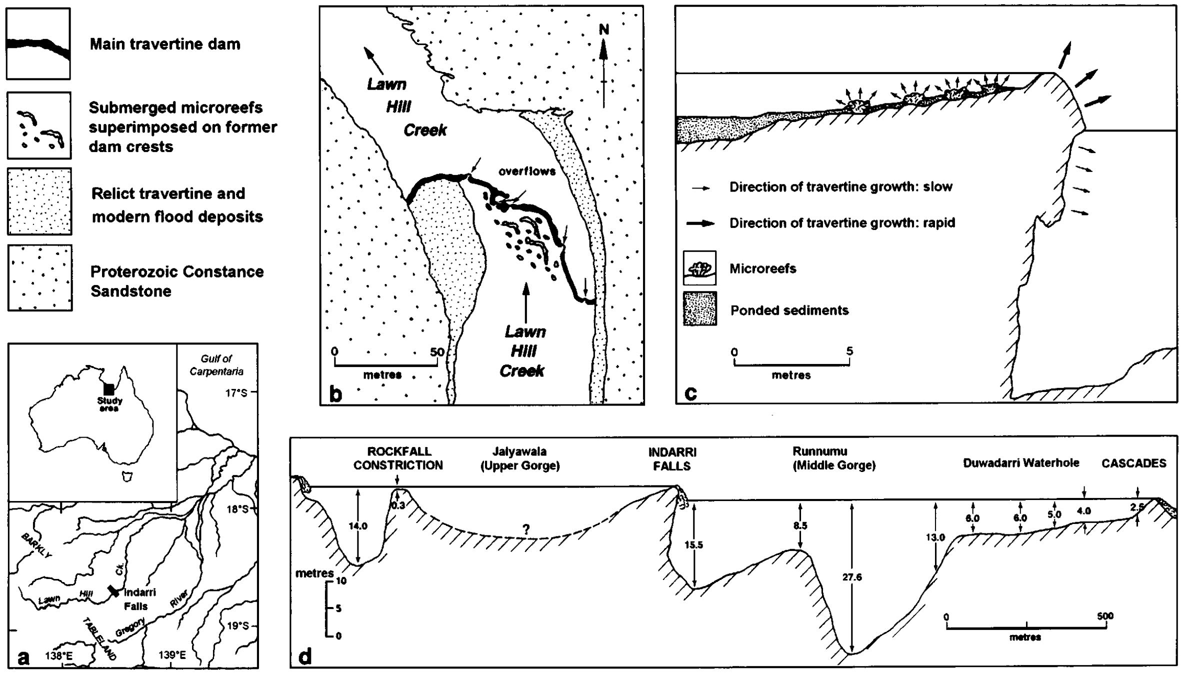

Figure 1. (a) The location of Lawn Hill Creek and Indarri Falls. (b) Plan of Indarri Falls showing the arcuate form of the travertine dam. (c) Schematic section through the dam showing the direction and rate of travertine growth. (d) The long profile of Lawn Hill Creek from the head of the Upper Gorge to the Cascades. The river depths (in metres) are correct at the points shown; the form of the remainder of the river bed is by interpolation.

Dam morphology

A bewildering array of classificatory schemes has been proposed for travertine deposits, and forms such as that of Indarrri Falls have been variously termed waterfalls or cascades (Chafetz and Folk, 1984), barrages (Pedley, 1990; Pentecost and Viles, 1994) and stream bed waterfalls and dams (Viles and Goudie, 1990). Although the height of the exposed wall of Indarri Falls is only *c.*2·5 m, the base of the Falls lies at least 11 m below the water surface, making the structure at least 13·5 m high (Figure 1c). The arcuate planform of the feature (Figure 1b) appears to be typical of travertine dams and cascades (for example, Ford (1989, p. 48)). In section, the dam is composed of three elements: an upstream-dipping ramp situated above the Falls, a horizontal overhang of at least 2 m on the dam face and a pseudo-plunge pool below the Falls (Figure 1c). For most of the year, water flow over the crest of the dam is confined to five narrow zones (Figure 1b) and the remainder of the exposed portion is dormant. Fan-shaped lobes or tongues of carbonate form beneath each overflow point (Figure 3). At the rear of the Falls a series of submerged microreefs (Schneider *et al.*, 1983) is superimposed on the shallow ramp section. These features are developed sub-parallel to the modern dam (Figures 1b and 1c). It is likely that the microreefs formed parts of earlier dam crests which have been drowned and abandoned by the downstream advance of the active crest (Figure 1b). The present dam appears to be composed entirely of travertine, although it is possible that the initial site of precipitation, now located some distance upstream of the Falls, was at a point of turbulence where the river flowed over an obstacle in the channel.

Carbonate precipitation processes

Lawn Hill Creek is fed by a series of surface and submerged springs. Analyses of samples from two of the surface springs show that their waters are just saturated with respect to calcite, with dissolved carbon dioxide values several hundred times that of the atmosphere (Table I). Upon emergence, carbon dioxide is expelled from the spring waters. This raises levels of dissolved calcium carbonate to a state of supersaturation with the result that, by the time the stream waters reach Indarri Falls, the physicochemical preconditions for carbonate

Figure 2. Indarri Falls and Lawn Hill Creek, northwest Queensland, Australia.

Table I. pH, carbon dioxide partial pressure and calcite saturation index data from water samples collected from two springs *c*.4 km upstream of Indarri Falls, Lawn Hill Creek, northwest Queensland, and from creek waters immediately upstream of the Falls.

Sampling date	Spring 1			Spring 2			Above Falls		
	pH	pP_{CO2}	SI_{cal}	pH	pP_{CO2}	SI_{cal}	pH	pP_{CO2}	SI_{cal}
22 June 1992	6·84	–1·11	0·00	6·93	–1·21	0·11	7·62	–1·95	0·68
19 April 1993	6·81	–1·14	–0·14	6·79	–1·12	–0·14	7·66	–2·00	0·70
27 October 1993	6·66	–0·94	–0·17	6·64	–0·93	–0·19	7·71	–2·00	0·82
19 April 1994	6·57	–0·84	–0·20	6·58	–0·85	–0·18	7·63	–1·93	0·78

pP_{CO2}=log partial pressure of carbon dioxide and SI_{cal}=log(K_{IAP}/K_{eq}), where K_{IAP} is the ion activity product of Ca^{2+} and CO_3^{2-} and K_{eq} is the equilibrium constant for calcite.

precipitation and hence travertine formation have been reached (Table I). Since the release of carbon dioxide from solution is greatest at sites of turbulence, the Falls represent a locus of extensive travertine deposition.

Travertines are almost always rich in microflora, particularly cyanobacteria, and many researchers (for example, Emeis *et al*. (1987) and Pedley (1992)) have stressed the importance of organic controls on travertine formation. There is clear evidence at Indarri Falls that biological factors play a role in carbonate precipitation. For example, both at Indarri Falls and along neighbouring travertine-depositing streams, aquatic caddis fly larvae construct nets on travertine surfaces and filter the water for food particles. The nets, which are arranged in linear arrays, act as substrates for calcite nucleation and growth. They increase the surface roughness of the

Figure 3. A lobe of travertine undergoing active deposition located at one of the five overflow points along the crest of Indarri Falls. The micromorphology of the lobe surface is controlled by the composition of aquatic flora which colonize the surface, which in turn is strongly dependent upon the hydraulic microenvironment. The horizontal features in the top right of the figure are strandlines which mark former water levels below the dam. Note the incision through the dam wall resulting from a drop in water levels below the Falls.

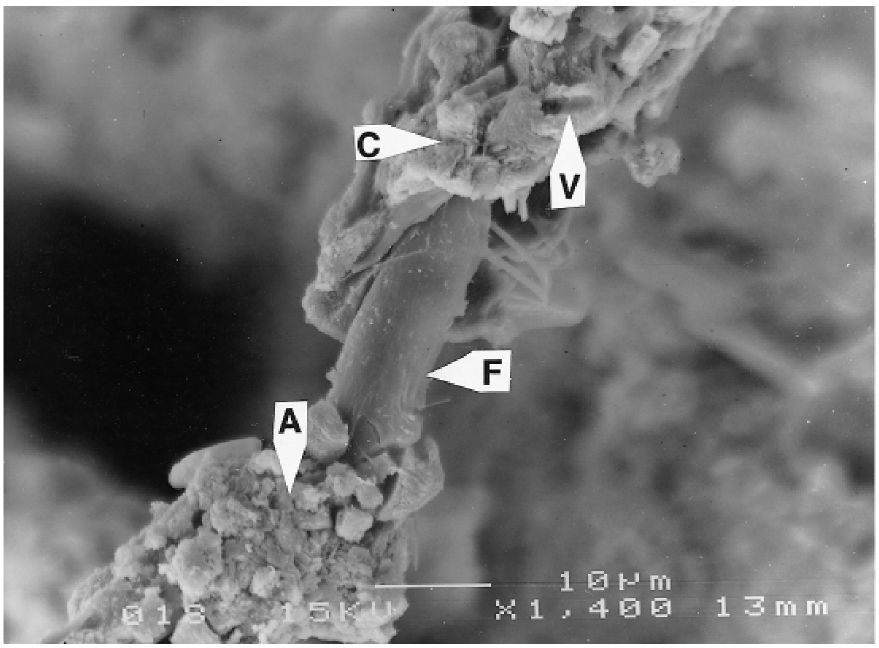

Figure 4. Scanning electron photomicrograph showing the encrustation of a filamentous ?cyanobacterium (F) by ?allochthonous micritic aggregates (A) and by incipient microsparite rhombs growing *in situ* (C). Calcite growth may be initiated by the entrapment of suspended seed crystals or by nucleation on the sticky surface of the microbe. In the latter instance, nucleation may be triggered inorganically or biochemically; in either case, nucleation and crystal growth occur in a bulk solution which thermodynamically favours carbonate precipitation. The cylindrical voids (V) mark former sites of cyanobacterial calcification. The sample was taken from the submerged surface of the dam at a depth of *c.*3 m.

travertine, enhancing turbulence and, by implication, outgassing, and considerably increasing the rate of travertine accumulation (Drysdale, 1993, 1995).

Similarly, the submerged face of the dam is colonized by algae (including diatoms), bacteria and cyanobacteria. Electron microscopic examination of surface material collected at a water depth of *c.*3 m has revealed that these microflora provide a supporting framework for calcite encrustation (Figure 4). Nevertheless, it is difficult to know whether the role of these micro-organisms in carbonate deposition is any more active than this given that the stream waters already thermodynamically favour carbonate precipitation.

Whilst the presence of larvae and other organisms in travertines is both universal and well-documented (for example, Pentecost and Riding (1986), Pedley (1992) and Folk (1993)), the significance of the Indarri Falls travertines is that microflora and microfauna persist all year round in the prevailing perennially warm conditions. One consequence of this is that variations over time in the nature of travertine deposition at a point are largely a function of small-scale hydrological changes or the stage of an organism's life cycle. Thus, a shift in hydrological conditions from seepage to turbulent flow might result in a change from precipitation in association with thick, hair-like masses of chlorophyta to deposition associated with cyanobacterial colonies. By contrast, short-term variations in the nature of deposition at a point in many temperate-zone travertines are largely a result of seasonal factors (for example, Dürrenfeldt (1978)).

The rate and nature of carbonate precipitation vary considerably across the dam. Along the dam wall, for example, growth takes place in both a vertical and a horizontal direction, with the greatest accretion occurring at the crest and on the downstream face. Here, the increase in velocity and the thinning of the water film encourage rapid outgassing of carbon dioxide (Varnedoe, 1965). This rapid growth is aided by the presence of *in situ* aquatic flora and allochthonous plant remains which provide the framework for calcium carbonate deposition. The morphological result of this is the characteristic horizontal overhang of the dam crest and the pseudo-plunge pool below the falls.

High rates of deposition also occur along the spillways which cross the dam crest and on the immediate downstream face of the dam. The geomorphic consequence of this is the fan-shaped lobes or tongues of carbonate which develop beneath each overflow point (Figure 3). It may be significant that these zones of rapid flow are also the environments favoured for the construction of caddis fly larvae nets, whereas areas receiving spray or affected by lapping waters remain uncolonized.

By contrast, rates of accretion on the submerged microreefs in the shallow ramp section at the rear of the Falls (Figures 1b and 1c) are relatively low. Experiments conducted in a neighbouring catchment have revealed rates of net carbonate accretion in such impounded water environments of $\leq 0{\cdot}4\,\mathrm{mm\,a^{-1}}$, up to two orders of magnitude slower than accumulation rates on active sections of travertine dam walls (Drysdale, 1995).

Weathering and erosion

The colonization of the dormant parts of the dam crest by plants is associated with the formation of a thin mantle of soil. The soil supplies carbon dioxide to the waters which percolate through pores in the travertine left by the decay of plant organic matter. The travertine thus experiences dissolution: voids are widened and karren develop on the dam surface. The accumulation of insoluble residues from the travertine probably encourages further dissolution by providing nutrients for plant growth. There is also evidence of case hardening, probably at least partly a result of carbonate reprecipitation by evaporation. Elsewhere, the travertine is weathered mechanically by root growth. During floods, the loosened material may be carrried downstream, exposing fresh surfaces to weathering and erosion. Floods may also scour the crest of the dam, whilst the lobes of carbonate which develop beneath the overflow points on the downstream face of the dam may be swept off during high-stage flows or may simply break off under their own weight. Apart from this, however, mechanical erosion appears to represent only a minor influence on what is essentially a constructional feature.

Hydrology

The progressive accumulation of travertine at the Falls has dramatically transformed the hydrology of the middle reaches of Lawn Hill Creek, resulting in a shift from fluvial to lacustrine conditions. The maximum recorded water depth upstream of the dam, 14 m (Figure 1d), is indicative of the extent of valley drowning resulting from travertine deposition. Below Indarri Falls, the water depth in the gorge is controlled by travertine accumulation at the Cascades, located about 1·5 km downstream (Figure 1d). The depth of water upstream of this deposit exceeds 27 m at one point (Figure 1d).

In addition to the longer-term changes in the hydrology of Lawn Hill Creek, there is considerable evidence of shorter-term fluctuations (Figure 3). Downstream of Indarri Falls, fossil travertine deposits drape the gorge walls up to almost 3 m above present water levels. These deposits are indicative of higher stream levels during earlier episodes of travertine accretion.

Finally, fossil lobes of carbonate preserved on the dam wall indicate that the locations of the overflow points

shift periodically. These changes are probably caused by differential rates of carbonate accretion along the crest of the dam. They may also result from the damming of spillways by entrapped debris such as branches and tree trunks, or by crest scour during floods.

Palaeoenvironmental significance

Given the size of Indarri Falls and the large proportion of its surface area which is either dormant, being degraded or accreting very slowly, the bulk of the dam is likely to have formed under conditions different to those of the present. The mere presence of travertine in a karst landscape indicates that sufficient water and carbon dioxide-producing biological activity must have been available to drive the karst processes necessary for travertine formation. Evidence in a neighbouring catchment indicates that travertine formation began at least as far back as 30 ka BP and continued through the last glacial maximum (Drysdale and Head, 1994), whilst at Riversleigh, 40 km to the south-southeast, carbonate deposition began as early as the Oligo-Miocene (Archer *et al.*, 1989; Megirian, 1993).

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